Novel Quadrifilar Helix Antenna Combining GNSS, Iridium, and a UHF Communications Monopole

P. G. Elliot, E. N. Rosario, R. J. Davis
The MITRE Corporation, Bedford, MA 01730

Abstract- **A GPS/GNSS/Iridium antenna co-located with a UHF communications monopole on a handset was developed to provide integrated communications and navigation capability. The GPS/GNSS/Iridium antenna is a folded Quadrifilar Helix Antenna (QHA) with novel features to improve frequency coverage compared to existing QHA designs. The GNSS frequencies covered include modernized GPS (L1, L2, L5), GLONASS, Galileo, and Beidou (Compass), spanning from 1164 to 1300 MHz and 1559 to 1611 MHz. The Iridium communications band (1611-1626 MHz) is also covered. This antenna can be co-located concentrically (co-axially) around a 225-400 MHz UHF monopole. Two QHA models were built and tested co-located with the UHF monopole on a handset box.**

I. INTRODUCTION

This paper describes an antenna designed for Global Navigation System (GNSS) and Iridium signals. The antenna can also be co-located with a UHF communications monopole on a handset to provide an integrated Communications - Navigation (Comm/Nav) antenna.*

The GPS/GNSS/Iridium antenna is a wideband folded Quadrifilar Helix Antenna (QHA) with novel features which improve frequency coverage compared to existing QHA designs. The GNSS frequencies covered include modernized GPS (L1, L2, L5), GLONASS, Galileo, and Beidou (Compass), spanning from 1164 to 1300 MHz and 1559 to 1611 MHz. The Iridium communications transmit and receive band (1611-1626 MHz) is also covered. This antenna can be co-located concentrically (co-axially) around a UHF monopole for 225-400 MHz communications. The QHA design simultaneously covers the GPS/GNSS/Iridium frequency bands with or without the UHF monopole inserted through it.

The primary design goal for the folded QHA was to maximize Right-Hand Circularly Polarized (RHCP) gain at all GNSS frequencies and Iridium at angles from zenith down to 10 degrees above the horizon. A QHA is well suited to this application since it provides excellent RHCP coverage at all azimuth and elevation angles, as well as low crosspolarization to reduce multipath.

The antenna patterns and gain are affected by the handset box upon which the antenna is mounted; for purposes of demonstration, the antennas were optimized and tested on a conductive handset box which was 8” long x 4” wide by 1.5” thick; no other ground plane was used. The diameter of the QHAs ranged from 0.75” to 1.5”, so that each could fit on top of a handset. A 10-inch long brass monopole or sleeve was included co-axially through the center of each QHA. The presence of the QHA around the monopole also increases the gain of a thin monopole by several dB over most of the UHF communications band.

* This task was supported by USAF GPS Directorate Contract No. FA8721-11-C-0001 Project No. 03116SC0-MR.

II. FOLDED QHA WITH NOVEL FEATURES

Fig. 1 shows the new folded QHA design and defines some dimensions. The QHA helix traces were made from copper tape placed on a thin Mylar sheet, which is compatible with printed-circuit volume production. The Mylar was then wrapped around a dielectric rod which filled the volume inside the helix. The dielectric is the white material seen inside the helix in the photos; it has an axial hole through the center of the dielectric for the optional UHF monopole or sleeve monopole.

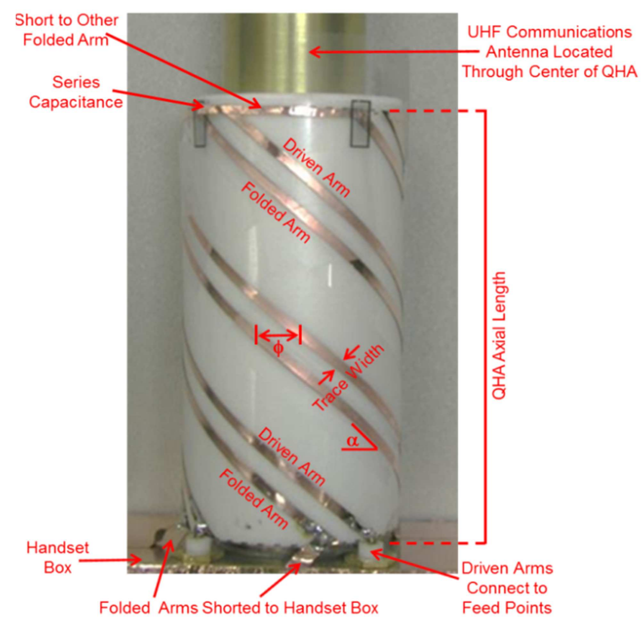


Fig. 1. Photo of Comm/Nav Folded QHA.

These QHA antennas have four 50-ohm feed points; each feeding one of the four helix driven arms, externally phased in quadrature for RHCP. The QHA also has four folded

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **APR 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Novel Quadrifilar Helix Antenna Combining GNSS, Iridium, and a UHF Communications Monopole**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **MITRE Corporation,202 Burlington Road,Bedford,MA,01730**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

arms; each folded arm is parallel to the driven helix arm and is shorted at the bottom of the folded arm to the handset conductive case, as seen in Fig. 1.

Use of folded arms for a QHA was previously reported to improve impedance match and bandwidth and/or to reduce size [1][2][3][4][5]. Further improvements to the folded QHA were developed under this task to extend the frequency coverage to include all GNSS and Iridium, and also to co-locate it with a UHF monopole.

Fig. 1 shows these novel QHA features. The connections between the driven and folded helix arms in the new QHA design are different from the prior works referenced above. One new feature is the "Series Capacitance," which adds capacitance at the top between each helix driven arm and its respective folded arm. This capacitance was produced by overlapping the copper traces as will be described. Also novel is the "Short to Other Folded Arm" seen at the top of the helix, which connects each helix driven arm to the folded arm of the adjacent helix (not shorted to its own folded arm as in [2]). Integration of the QHA coaxially around a UHF monopole communications antenna is also new, and it was not obvious the QHA would work well with the monopole present until it was tested under this effort.

Tables I and II list dimensions and parameters for each QHA design. The length of the dielectric rod was about 1 mm longer than the QHA Helix Axial Length.

Column e is the Helix Pitch which is the axial length if the helix were extended for 1 full turn (the helix is less than 1 full turn).

Column f is the Helix Pitch Angle α defined in Fig. 1 as the slope of helix trace measured from horizontal.

Column g is Degrees of Rotation to Folded Arm ϕ shown in Fig. 1; it is the circumferential angle about the center axis of the helix separating the driven helix arm from the folded arm, center to center of the traces.

Column i is the Helix Trace Length in wavelengths; it is the length along each driven arm as it winds around, from the feed point at the bottom, up to the top of the helix, divided by the free-space wavelength at 1.4 GHz, which is the approximate center of the GNSS frequency band .

Column j is the Helix Trace Width of the copper trace used for each helix arm. A trace width as narrow as 0.5 mm (0.020") was found to improve performance for these folded QHA.

Table I. QHA Prototypes Computer Modeled, Built and Tested.
Dielectric Rod is Rohacell with Relative Permittivity ε_r =1.07

a.	b.	c.	d.	e.	f.	g.	h.	i.	j.
Prototype Name	QHA Diameter	QHA Helix Axial Length	UHF Brass Monopole Diameter	Helix Pitch	Helix Pitch Angle α	Degrees Rotation Folded Arm ϕ	Number of turns for each helix	Helix Trace Length, wvlgth	Helix Trace Width
Air-loaded 1.5" x 2.9"	1.50" (38.1mm)	2.913" (74mm)	1.00" (25.4mm)	3.870"	39.2°	24°	0.753	0.547 λ_o	0.079" (2mm)
Air-loaded 1.0" x 3.2"	1.00" (24.5mm)	3.189" (81mm)	0.125" (3.2mm)	3.338"	46.4°	24°	0.955	0.522 λ_o	0.079" (2mm)

Table II. QHA Prototypes Computer Modeled only (not built).
Dielectric Rod is EccoStock HiK with Relative Permittivity ε_r =4.0

a.	b.	c.	d.	e.	f.	g.	h.	i.	j.
Prototype Name	QHA Diameter	QHA Helix Axial Length	UHF Brass Monopole Diameter	Helix Pitch	Helix Pitch Angle α	Degrees Rotation Folded Arm ϕ	Number of turns for each helix	Helix Trace Length, wvlgth	Helix Trace Width
Diel-loaded 1.0" x 2.2"	1.00" (24.5mm)	2.244" (57mm)	0.125" (3.2mm)	3.103"	44.3°	25°	0.723	0.381 λ_o	0.020" (0.5mm)
Diel-loaded 0.75"x 2.4"	0.75" (19.05mm)	2.441" (62mm)	0.125" (3.2mm)	2.631"	47.7°	30°	0.928	0.391 λ_o	0.020" (0.5mm)

III. QHA PROTOTYPE RESULTS

The two QHA in Table I were built and tested. They used a Rohacell foam dielectric material with a very low dielectric constant (ε_r =1.07) so they are approximately air-loaded.

The QHA antennas were externally phased for RHCP using two quadrature hybrids and one 180 hybrid. The loss through this combiner network is approximately 2 dB, which is incorporated in, and has already reduced, all the measured gains and patterns shown in this paper.

The first QHA in Table I is shown in Fig. 1. This QHA is 1.5” wide and 2.9” long, so it does not exceed the 1.5” thickness of the handset case. It encircles a 1” diameter, 10” long metal cylinder such as for a UHF sleeve monopole [6]. The bottom of the sleeve was soldered to the handset.

The measured RHCP gain patterns of this QHA are plotted in Figs. 2a through 2d in two cardinal planes. Fig. 3 shows the gain at zenith for all GNSS and Iridium frequencies. The measured zenith gain at L1 is 0.8 dBic and at Iridium it is 0.3 dBic. At L2 and L5 the gain is about -1.4 dBic. Fig. 4 shows the Return Loss (S11) at each input port for this QHA which shows a dual-band very low return loss, which shows a very good impedance match. The measured crosspolarization level for all the QHA was around -20 dBic. The low-angle coverage of about -5 dBic at 10° elevation is also better than most other types of FRPAs, that is a typical benefit of a QHA type of antenna. This gain performance is good, especially at low elevation angles, considering the presence of the wide 1” diameter metal cylinder within the 1.5” diameter QHA. Increasing the diameter of the brass cylinder further was found to reduce the gain of the QHA.

It is interesting to note that the individual port S11 resonances in Fig. 4 do not always occur at exactly the same frequencies as the maximum gain shown in Fig. 3. This is probably mainly due to mutual coupling between the four feed ports, which will affect the impedance and return loss when all four ports are phased and driven simultaneously for RHCP. Additional prototyping might be able to improve the gain performance.

The 2nd QHA in Table I has the same topology as shown in Figure 1, but the diameter was less than for the 1st QHA since the inserted monopole was much thinner as shown in column d. The 2nd QHA is 1.0” wide by 3.2” long; it encircles a monopole which is 0.125” diameter and 10” long.

As a result of the thinner monopole, the 2nd QHA was able to achieve better performance than the 1st QHA. The measured RHCP gain patterns of this QHA are plotted in Figs. 5a through 5d. Fig. 6 shows the gain at zenith for all GNSS and Iridium frequencies. The measured peak gain at L1 is 0.8 dBic and at Iridium it is 1.7 dBic. At L2 the gain is 1.4 dBic and at L5 it is 0.8 dBic. Fig. 7 shows the Return Loss (S11) at each input port of this QHA, the return loss is low which is shows a good impedance match. However, it is seen in Figs. 6 and 7 that the best return loss and gain performance were obtained at a much higher frequency (around 1.75 GHz in Fig. 7), so with additional tuning it would probably be possible to move that high gain resonance closer to the L1 and Iridium frequency.

Patterns were also measured for the 2nd QHA without any UHF Monopole inserted through it. Those patterns are not shown here due to space limitations, but the QHA performance is similar to the results shown here, and can be reoptimized with a slight re-tuning of the QHA capacitance to compensate for the removal of the monopole.

The 2nd QHA provided much better size - performance tradeoff for GNSS and Iridium than existing folded QHAs described in the literature. The QHA reported in [2] is 5.0” long and 1.34” diameter and does not cover the L5 frequency. The QHA in [3] is 3.07” long and 1.42” diameter and only covers L1/L2, not L5 nor other GNSS frequencies nor Iridium. The QHA designs reported in [4] and [5] cover only one narrow frequency band. A prior L1/L2 dual-band trap-loaded QHA [7][8] is about 5” long and covers only L1 and L2. It is also not specifically stated in any of these prior papers whether the loss through the quad combiner is included in the reported gain or not. Also, none of the other QHA investigated co-locating a monopole with the QHA.

The performance of the 2nd QHA was very insensitive to the impedance between the base of the monopole and the handset case: whether open or short circuited or a small gap. So it is expected that this impedance will not have a significant effect on the QHA GNSS and Iridium performance.

Electromagnetic computer modeling software was used to optimize the QHA; specifically High Frequency Structure Simulator (HFSS) with the Distributed Solve Option from Ansys Corporation. The HFSS computed results for the QHA are not included in this paper due to space limitations. The computed patterns are similar to the measured patterns except the computed gain is about 2 to 4 dB higher near zenith than the measured gain. Only 2 dB of that discrepancy is due to quad combiner loss used to form the RHCP for the measurements. The remaining 0 to 2 dB discrepancy is probably due to inaccuracies in the HFSS computer simulation, imperfections in the prototype construction, and measurement tolerances. The HFSS computed S11 curves show a double dip resonance as seen in the measured results in Figs. 4 and 7, although the frequency is often shifted a little in the optimized computed curves, which suggests that further improvements in performance are possible.

The two QHA in Table II were computer modeled but not tested. They have a dielectric material with ε_r =4. The computer models predicted coverage of the GNSS and Iridium frequencies, with or without the thin UHF monopole. Due to the dielectric loading (εr=4.0) the bandwidth is narrower and coverage at L5 is lower gain than the larger air-loaded QHA results shown above. Other dielectric constants as high as 9 and 15 were also tried, but better results were obtained using the lower dielectric constants for these wideband designs

IV. UHF MONOPOLE

A 10-inch long brass monopole (0.125" diameter) or monopole sleeve (1.0" diameter) was included co-axially through the center of each QHA for the measurements in order to determine their effect on the GNSS and Iridium performance of the QHA. The performance of UHF monopoles is widely documented [9], and the performance of a novel compact sleeve monopole at UHF is described in [6].

To examine the effect of the QHA on the monopole performance, the gain of the thin UHF monopole was computed with and without the QHA. It was found that the presence of the QHA around the thin monopole improves the impedance match and increases gain of the monopole by several dB towards the horizon, over most of the UHF communications band. The isolation or coupling between the UHF monopole and QHA ports was also computed and found to be about -45 dB at GNSS frequencies.

V. SERIES CAPACITANCE

As mentioned earlier and shown in Fig. 1, a novel feature introduced in this paper is the "Series Capacitance" added between each helix driven arm and it's respective folded arm. This capacitance was produced by overlapping two copper traces, separated by a thin layer of Mylar, to form a small parallel-plate capacitor. This was found to be a more reliable and repeatable method to include very small capacitances in the prototypes than soldering surface-mount capacitors by hand. It also allowed the capacitance to be trimmed to tune the impedance match and to maximize the gain of the antenna at the desired frequencies. The same capacitance was used for each of the four helixes of the QHA. The desired capacitance was first estimated using HFSS modeling, and then it was adjusted empirically by trimming the capacitor overlap length in the prototypes. However, the amount of capacitance was not fully optimized in the prototypes due to time limitations, so it is possible that additional lab work could improve the results.

Each parallel plate capacitance (without fringing effects) is given by:

$$C = K*Eo*A/D$$

where:

K = 3.2 is the dielectric constant (relative permittivity) of the polyester film (Mylar) sandwiched between the overlapping traces to form each capacitor

Eo is Permittivity of free space (8.854×10^{-12} F/m, which equals 0.2248×10^{-12} F/inch).

A is the overlapping area of the traces,

D is the distance separating the overlapping traces.

For example, if the circumferential top copper trace is 0.030" wide, with an overlap length of 0.060", then the overlap area is 0.0018 square inches. The Mylar is 0.1mm thick (0.00394") with K=3.2 so the capacitance is 0.33 pF from the above equation which does not include fringing effects. For fringing effects [10] add about 0.07 pF for this size capacitor, so each capacitor is about 0.4 pF, which is a typical value used for each of the four capacitors in the QHA, although it differed somewhat for each QHA design.

VI. CONCLUSION

A GPS/GNSS/Iridium QHA co-located with a UHF monopole can provide integrated communications and navigation capability. The QHA utilizes novel features to improve frequency coverage compared with existing QHAs, and the QHA also significantly improves the UHF gain of the monopole.

ACKNOWLEDGMENT

This task was supported by USAF GPS Directorate. We also thank Dr. Keith McDonald, Janet Werth, and Dr. Basrur Rama-Rao of MITRE for task management, technical recommendations, and review of this paper.

REFERENCES

1. A. Sharaiha, Y. Letestu, and J.C. Louvigne, "Broadband Helical Antenna," French Patent PCT/FR03/02774, 2002.
2. Letestu, Y., A. Shariha; "Broadband Folded Printed Quadrifilar Helix Antenna"; IEEE Transactions on Antennas & Propagation, Vol. AP-54, n.5. May 2006, pp. 1600-1604.
3. Rabemanantsoa, J., A. Shariha; "Small-folded, Printed Quadrifilar Helix Antenna for GPS Applications"; 14th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM) and the American Electromagnetics Conference (AMEREM), 2010.
4. Bhandari, B., S. Gao, and T. Brown; "Meandered Variable Pitch Angle Printed Quadrifilar Helix Antenna"; 2009 Loughborough Antenna and Propagation Conference, 16-17 Nov. 2009. Loughborough, UK.
5. A. Petros and S. Licul, "Folded Quadrifilar Helix Antenna," in IEEE Antennas and Propagation Symposium, v.4., 2001, pp.569-572.
6. Rama-Rao, B., Jeffrey M. Elloian, E. N. Rosario, and R. J. Davis; "Ferrite Loaded UHF Sleeve Monopole Integrated with a GPS Patch Antenna for a Handset". Submitted for publication in " Microwave and Optical Technology Letters".
7. Lamensdorf, D.; Smolinski, "Dual-band quadrifilar helix antenna"; IEEE Antennas and Propagation Society Symposium, 2002. v.3, pp.488 – 491.
8. Lamensdorf D., M. Smolensk; "Dual Band Quadrifilar Helix Antenna" U.S. Patent # 6653987 Nov. 2003.
9. Chen, To Tai, "Dipoles and Monopoles" in "Antenna Engineering Handbook", Second Edition; Editors: R.C. Johnson, H. Jasik; McGraw-Hill Book Co. 1984, Chapter 4.
10. http://chemandy.com/calculators/rectangular-capacitor-calculator.htm

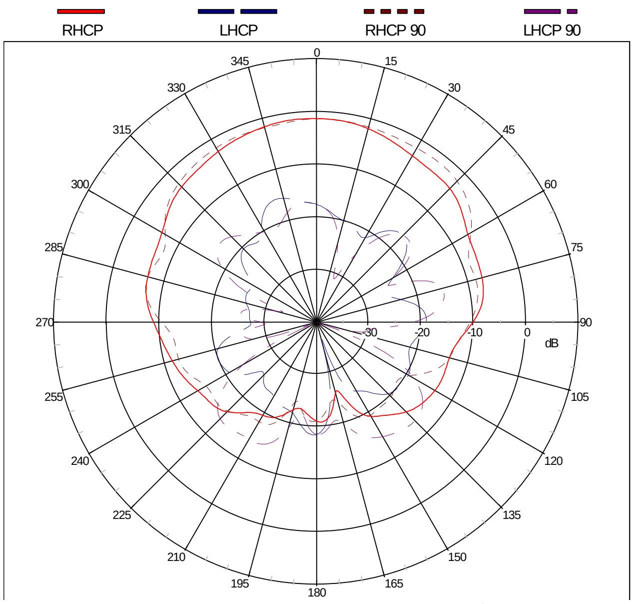


Fig. 2a. 1.176 GHz Measured RHCP Gain patterns for Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case.

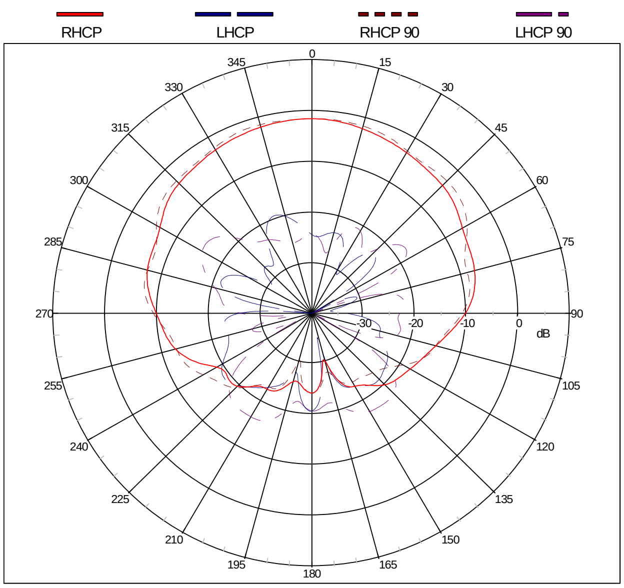
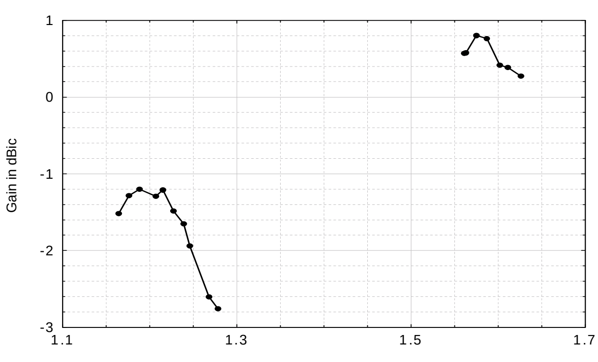


Fig. 2b. 1.227 GHz Measured RHCP Gain patterns for Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case



. Fig. 3. Measured RHCP Gain near Zenith for Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case.

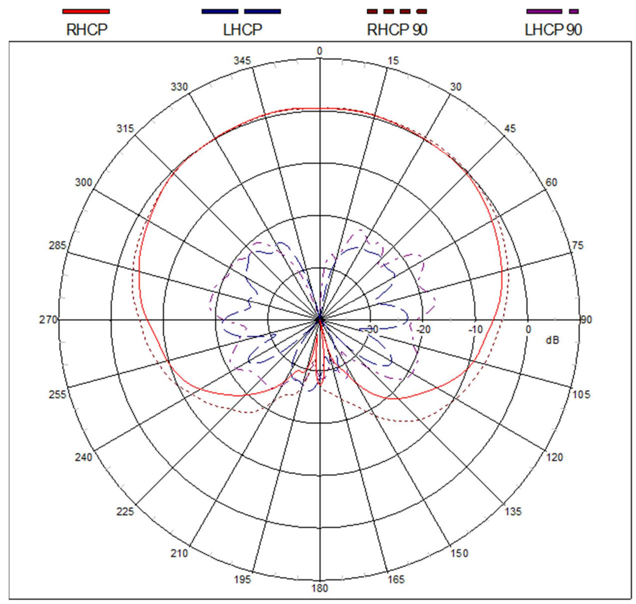


Fig. 2c. 1.575 GHz Measured RHCP Gain patterns for Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case.

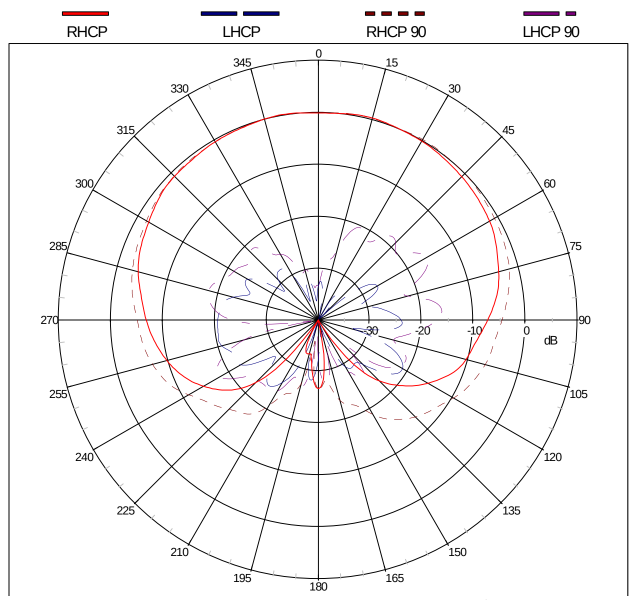


Fig. 2d. 1.626 GHz Measured RHCP Gain patterns for Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case.

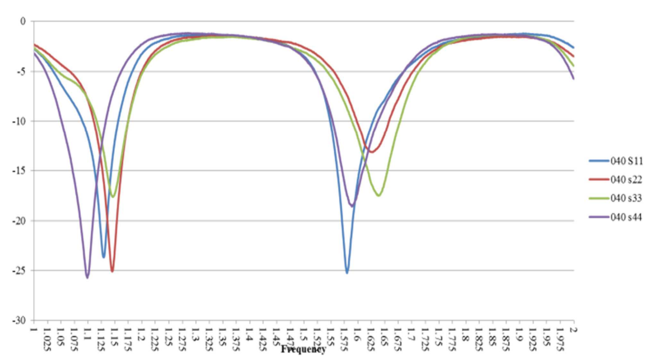


Fig. 4. Measured Return Loss S11 at each Input Port of Air-loaded 1.5” x 2.9” QHA Encircling Metal Cylinder and on Handset Case.

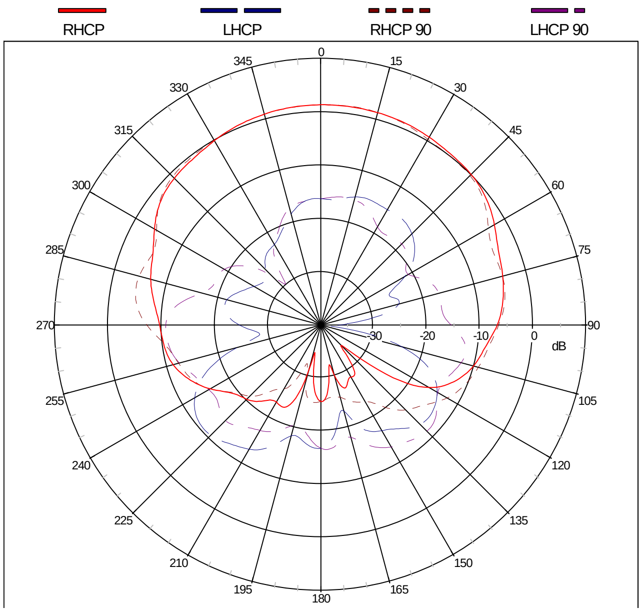


Fig. 5a. 1.176 GHz Measured RHCP Gain patterns for Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.

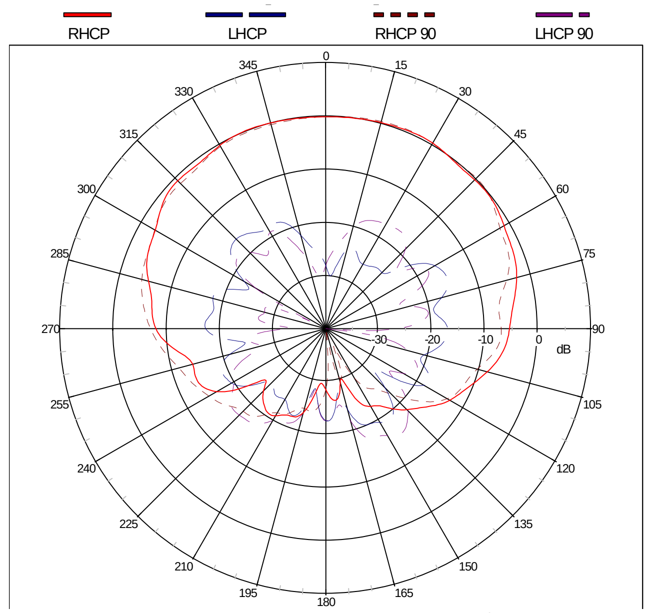


Fig. 5c. 1.575 GHz Measured RHCP Gain patterns for Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.

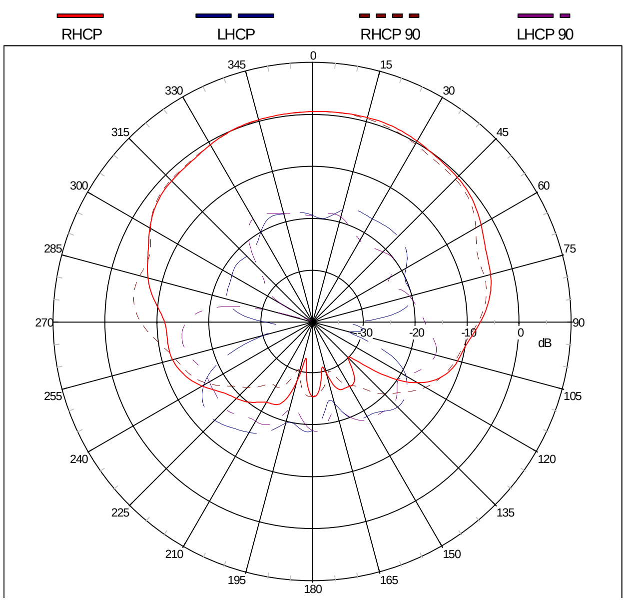


Fig. 5b. 1.227 GHz Measured RHCP Gain patterns for Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.

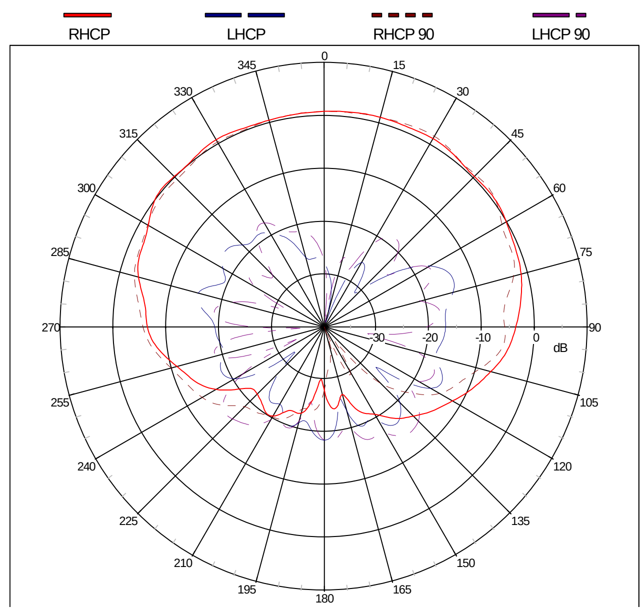


Fig. 5d. 1.626 GHz Measured RHCP Gain patterns for Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.

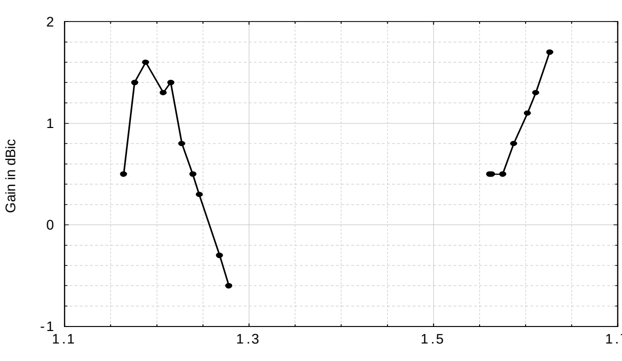


Fig. 6. Measured RHCP Gain near Zenith for Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.

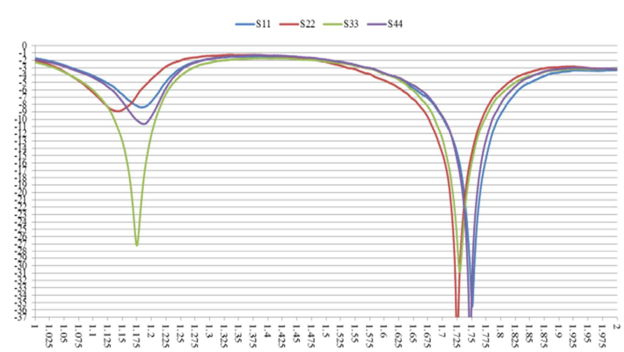


Fig. 7. Measured Return Loss S11 at each Input Port of Air-loaded 1.0” x 3.2” QHA Encircling 0.125” diam Monopole on Handset Case.